EXPERIMENTAL VERIFICATION OF AN OPTIMAL LINEAR CONTROLLER FOR A FLEXIBLE STRUCTURE

William Burke Harrington, Jr.-Lieutenant Commander, United States Navy
B.S., Marine Engineering, United States Naval Academy, 1985
Aeronautical and Astronautical Engineer-December 1995
Advisor: Brij N. Agrawal, Department of Aeronautics and Astronautics

Nanometer accuracy in many space applications requires that sensors be isolated from vibration disturbances by the main spacecraft body. The Flexible Spacecraft Simulator (FSS) at the Naval Postgraduate School is designed for testing multiple control system designs. The experimental setup simulates a microgravity environment for a flexible Structure. A twenty-four state finite element model is used to characterize the flexible appendage. Piezoelectric ceramic wafers bonded to the structure are the actuators and sensors. A *VisionServer* external infrared camera provides direct feedback of the flexible structure's elbow and tip displacements to sub-millimeter accuracy. A Multiple-Input-Multiple-Output (MIMO) Linear Quadratic Gaussian (LQG) controller is experimentally compared with a Positive Position Feedback/Velocity feedback controller. The damping is increased on the order of 825% for both control implementations. The objective is to minimize the disturbance of the tip of the flexible structure, representing the reflector support point.

ORBITAL PERTURBATION ANALYSIS OF EARTH-CROSSING ASTEROIDS

Wade E. Knudson-Lieutenant Commander, United States Navy
B. S., United States Naval Academy, 1984
Aeronautical and Astronautical Engineer-December 1995
Advisor: I.M. Ross, Department of Aeronautics and Astronautics

Earth-Crossing Asteroids (ECAs) are those asteroids whose orbit cross-section can intersect the capture cross section of the Earth as a result of secular gravitational perturbations. This thesis provides a framework for understanding the origin, nature, and types of ECAs. The change in velocity requirements to achieve a two Earth radii deflection for long- and short-term warning scenarios are developed. Next, a method of developing hypothetical Earth colliding asteroid orbits is presented. These hypothetical orbits are used in two ways: (1) to evaluate the ability of *Dance of The Planets*, a solar system simulation model developed by Applied Research and Consulting, Inc., to accurately propagate orbits of imported asteroid orbits, and (2) to analyze the sensitivity of deflection distance to variation in deflection angle and orbital parameters of a given orbit. Inaccuracies during importation of data precluded the use of *Dance of the Planets* for the purpose of sensitivity analysis. The program does provide an excellent tool for visualization of ECA scenarios. Consequently, a simpler orbital model was developed to provide a Earth miss distance sensitivity analysis. With one asteroid orbital period warning the minimum change in velocity to deflect an asteroid two Earth radii is approximately 0.135 m/s and the optimal deflection is along the flight path. Maximum deflection occurs when the deflection is applied at perihelion. The miss distance decreases markedly with increase in true anomaly until it is a minimum at aphelion.

AN ANALYSIS OF SPACECRAFT DYNAMIC TESTING AT THE VEHICLE LEVEL

Alan Douglas Scott-Commander, United States Navy
B.S., United States Naval Academy, 1981
Aeronautical and Astronautical Engineer-June 1996
Advisor: Brij N. Agrawal, Department of Aeronautics and Astronautics
Second Reader: Barry S. Leonard, Department of Aeronautics and Astronautics

The U.S. space industry has accumulated a vast amount of expertise in the testing of spacecraft to ensure these vehicles can endure the harsh environments associated with launch and on-orbit operations. Even with this corporate experience, there remains a wide variation in the techniques utilized to test spacecraft during the development and manufacturing process, particularly with regard to spacecraft level dynamics testing. This study investigates the effectiveness

of sinusoidal vibration, random vibration, acoustic noise and transient methods of spacecraft dynamic testing. An analysis of test failure and on-orbit performance data for acceptance testing indicates that the acoustic test is the most perceptive workmanship screen at the vehicle level and that additional dynamics tests do not result in an increase in acceptance test effectiveness. For spacecraft qualification, acoustic testing is almost universally employed for qualification in the high frequency environment. For the low frequency environment, data collected from a variety of spacecraft test programs employing sinusoidal sweep, random vibration and transient testing methods shows that a transient base excitation provides the most accurate simulation for the purpose of design verification. Furthermore, data shows that sinusoidal vibration testing provides an unrealistic simulation of the flight environment and results in an increased potential for over testing.

EVALUATION OF THE STRAIN ENERGY DENSITY METHOD OF NOTCH STRESS CONCENTRATION CALCULATIONS IN THE PLASTIC RANGE

Grant B. Stephenson-Lieutenant, United States Navy
B.S., United States Naval Academy, 1988
M.S., Naval Postgraduate School, 1995
Aeronautical and Astronautical Engineer-March 1996
Advisor: Gerald H. Lindsey, Department of Aeronautics and Astronautics

Accurate stress and strain calculations at a notch usually require a nonlinear finite element analysis when local yielding has occurred. The strain energy density hypothesis is a method to predict these stress and strain values. This method proposes that the plastic strain energy density is equivalent to the strain energy density found assuming the material to be entirely elastic. This hypothesis was evaluated using the finite element method, which was tested by comparing two exact solutions of elastic and elasto-plastic problems, to calculate the stress and strain field for two notched plates of varying widths under elasto-plastic loading. For both geometrics, a plane stress and plane strain analysis was performed.

The elasto-plastic strain energy density from the finite element method was found to be greater than that predicted by this proposal, which in turn resulted in under-predicting the local stresses and strains. This difference was greater for the plane stress condition than for the plane strain condition. Comparisons were also made with notch stresses based on the Neuber method. The two methods appear to give an upper and lower bound to the actual stresses and strains. By combining the results of the strain energy density method and the Neuber method, reasonably accurate estimates of stress and strain values can be obtained.

PERFORMANCE AND OPTIMAL PLACEMENT OF PIEZOCERAMIC ACTUATORS FOR SHAPE CONTROL OF A CANTILEVER BEAM

Kirk E. Treanor-Lieutenant, United States Navy
B.S., University of California Los Angeles, 1987
Aeronautical and Astronautical Engineer-June 1996
Advisor: Brij N. Agrawal, Department of Aeronautics and Astronautics
Second Reader: John L. Meyer, Department of Aeronautics and Astronautics

Shape control of spaceborne antennas can provide the ability to correct for effects such as thermal distortion and manufacturing errors as well as control the shape of an antenna's radiated beam. This thesis examines the performance of piezoceramic actuators in producing static deformation of a cantilever beam and analyzes the optimal placement of actuators to best approximate a desired deformation profile. Predictions of actuator effectiveness at producing curvature are developed using an Euler-Bernoulli model. An algorithm to determine the optimal locations and input voltages for a fixed set of actuators to achieve a desired deformation profile of a cantilever beam using embedded Nelder and Mead simplex search routines is presented and evaluated for two shape functions and various combinations of actuators. Experimental measurements show that the Euler-Bernoulli model provides a reasonable prediction of actuator performance at low input voltage but does not account for nonlinear behavior of the piezoeceramic and the effects of hysteresis and transverse stresses. Further experiments demonstrate the ability of four piezoceramic actuators to pro-

duce an approximation of a parabolic deformation profile of a cantilever beam and illustrate the importance of considering these effects in determining the required actuator input voltages.

INTEGRAL HYBRID-BOOST/SOLID-FUEL RAMJET PROPULSION FOR LIGHTWEIGHT TACTICAL MISSILES

Paul C. Woods-Lieutenant, United States Navy
B.S., University of Washington, 1987
Aeronautical and Astronautical Engineer-December 1995
Advisor: D. W. Netzer, Department of Aeronautics and Astronautics

An investigation was conducted to determine the feasibility of a small, low-cost, caseless, hybrid-booster/solid-fuel ramjet (H/SFRJ) that utilizes a common fuel grain and has no ejectables. Performance of an air-to-ground missile with a solid propellant booster and SFRJ sustainer, capable of being fired from an unmanned aerial vehicle or helicopter was obtained using an Air Force computer code. A H/SFRJ motor was then designed analytically and compared to the generated computer output. The results showed that a H/SFRJ that has performance equal to a solid-booster SFRJ is feasible. The final missile design had a range of 20 nm, a flight Mach number of 2.0, a diameter and length of 5 and 99 inches respectively, and weighed 82 lb. Caseless hybrid rockets with erodible nozzles were tested to validate assumptions made in the design analysis. In addition, transition from hybrid-rocket booster to solid-fuel ramjet sustainer was demonstrated.

MULTIRESOLUTION IMAGE RECOGNITION USING THE WAVELET TRANSFORM

William M. Peyton, Jr.-Lieutenant, United States Navy
B.S., University of Pennsylvania, 1988
Electrical Engineer Degree-June 1966
Master of Science in Electrical Engineering-June 1996
Advisor: Murali Tummala, Department of Electrical and Computer Engineering
Second Reader: Ralph Hippenstiel, Department of Electrical and Computer Engineering

With the growth of information dissemination over digital communication networks, much research has been devoted to compressing digital image information for efficient transmission. The ability to adjust the desired resolution of an image as the available bandwidth on the network changes allows the user to control the flow of data according to the resources available. In this thesis we integrate multiresolution image compression methods with image recognition. Features of grayscale and binary images of text characters and aircraft line drawings are described using wavelet transform coefficients, wavelet transform subband energy, and Fourier transform coefficients. Transmission of these features over a digital communication link is simulated, and multiresolution recognition performance in the presence of channel noise is presented.

THE EFFECT OF THERMOMECHANICAL PROCESSING ON THE TENSILE PROPERTIES AND MICROSTRUCTURE OF A 6061 AL-AL_2O_3 METAL MATRIX COMPOSITE

Michael Alan Ballou-Lieutenant, United States Navy
B.S., United States Naval Academy, 1989
Mechanical Engineer-December 1995
Advisor: Terry R. McNelley, Department of Mechanical Engineering

This work includes a comprehensive analysis of the effect of thermomechanical processing (TMP) history on the microstructure and properties of 10 and 20 volume percent 6061 Al-Al_2O_3 discontinuous metal matrix composites (MMCs). Materials in which cold drawing and annealing operations were included in the TMP demonstrated increased ductilities for a given strength level when compared to materials which were processed by hot extrusion only. Microstructural analysis provided clear evidence of the absence of damage to reinforcing particles during TMP and of load transfer to these particles during subsequent straining. Failure during tension testing resulted from the ductile tearing of the matrix as voids, initiated by the cracking of reinforcement particles, joined together. A distinct microstructural difference related to processing history was the development of a strongly fibered particle distribution in materials experiencing low temperature drawing operations. In order to conduct an analysis of the mechanisms by which the particles are redistributed and reoriented during processing, a channel compression die was constructed which allowed processing to be simulated by compressive straining on a mechanical testing machine. This allowed careful control of the processing parameters. An analysis of the effects of processing temperature on particle redistribution and reorientation was conducted.

INTERACTION OF A SWIRLING JET WITH A FREE SURFACE

Michael S. Feyedelem-Lieutenant, United States Navy
B.S.N.E., Purdue University, May 1989
Mechanical Engineer-March 1996
Master of Science in Mechanical Engineering-March 1996
Advisor: T. Sarpkaya, Department of Mechanical Engineering

The turbulent flow field of a swirling jet issuing from a nozzle, beneath and parallel to a free surface has been studied in as much detail as possible using a three-component laser Doppler velocimeter and flow visualization. The results have shown that the swirl leads to the faster spreading and quicker mixing of the jet. For strongly swirling jets (S = 0.522), the similarity is not reached within ten diameters downstream. The results have also shown that both the axial and tangential velocity components decrease outward from the jet axis, naturally leading to centrifugal instabilities. This, in turn, leads to the creation of large scale coherent structures at the periphery of the jet, particularly when it is in the vicinity of the free surface. The turbulent shear stresses exhibit anisotropic behavior, the largest always being in the plane passing through the jet axis. The change of TKE with S is not monotonic. It is maximum for S = 0.265, smallest for S = 0.50, and has an intermediate value for S = 0.522. This is due to the occurrence of vortex breakdown and the resulting intensification of the turbulence within the jet prior to its exit from the nozzle.

OPTIMAL SOLUTION SELECTION FOR SENSITIVITY-BASED FINITE ELEMENT MODEL UPDATING AND STRUCTURAL DAMAGE DETECTION

Jay A. Renken-Lieutenant Commander, United States Navy
B.S., University of Illinois, August 1983
Mechanical Engineer-December 1995
Master of Science in Mechanical Engineering-December 1995
Advisor: Joshua H. Gordis, Department of Mechanical Engineering

The finite element model has become the standard way in which complex structural systems are modeled, analyzed, and the effects of loading simulated. A new method is developed for comparing the finite element simulation to experimental data, so the model can be validated, which is a critical step before a model can be used to simulate the system.

An optimization process for finite element structural dynamic models utilizing sensitivity based updating is applied to the model updating and damage detection problems. Candidate solutions are generated for the comparison of experimental frequencies to analytical frequencies, with mode shape comparison used as the selection criteria for the optimal solution. The method is applied to spatially complete simulations and to spatially incomplete experimental data which includes the model validation of a simple airplane model, and the damage localization in composite and steel beams with known installed damage.

STUDIES ON SUBMARINE CONTROL FOR PERISCOPE DEPTH OPERATIONS

John Vincent Tolliver-Lieutenant, United States Navy
B.S., Montana State University, 1988
Master of Science in Mechanical Engineering-September 1996
Mechanical Engineer-September 1996
Advisor: Fotis Papoulias, Department of Mechanical Engineering

Requirements for submarine periscope depth operations have been increased by integration with carrier battle groups, littoral operations, and contributions to joint surveillance. Improved periscope depth performance is therefore imperative. Submarine control personnel rely on a large number of analog gauges and indications. An integrated digital display system could enhance the ergonomics of the human control interface and display additional parameters. This thesis investigates the required feedbacks for robust automatic depth control at periscope depth, and thus indirectly determines the additional parameters desired for an integrated display.

A model of vertical plane submarine dynamics is coupled with first and second order wave force solutions for a particular submarine full form. Sliding mode control and several schemes of state feedback are used for automatic control. Head and beam seas at sea states three and four are investigated. The automatic control effectiveness provides insight into the indications used by the ship's control party in operations at periscope depth. One possible display system is proposed, with several additional enhancements to improve ship's safety, reduce operator fatigue, and enable accurate reconstruction of the events leading to a loss of depth control.